Technical Report Documentation Page

1. REPORT No.

426028-2

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

The Application Of A Nuclear Soil Gage To Construction Control

5. REPORT DATE

January 1966

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

D.R. Howe

8. PERFORMING ORGANIZATION REPORT No.

426028-2

9. PERFORMING ORGANIZATION NAME AND ADDRESS

State of California
Department of Public Works
Division of Highways
Materials and Research Department

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT & PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

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While these studies have studies have examined many facets of the operation of nuclear devices, including their experimental use on construction projects (2) (4), the gages had not yet been tried as the sole means of determining in-place density and moisture on a going contract. As a consequence very little, if any, information has been derived concerning the problems which might arise from the implementation of the devices by contract specification. The administrative aspects, creation of a practical test method and other factors such as the training of personnel, health safety, equipment durability, etc., could all affect the feasibility of nuclear gages for use in compaction control. It was therefore decided that the overall nuclear density program had come to a stage where a pilot study, using a nuclear soil gage for actual construction control, was indicated.

As a result of this decision, inquiries were made in several districts regarding a prospective project for this study. In making the selection it was necessary to consider factors such as project timing, type and scope of work, location, etc.

17. KEYWORDS

18. No. OF PAGES:

40

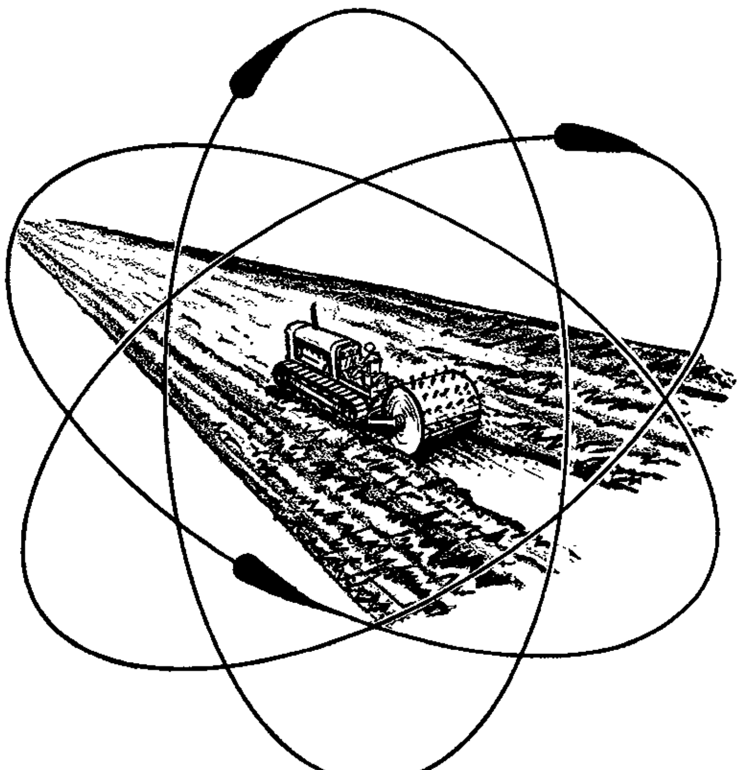
19. DRI WEBSITE LINK

http://www.dot.ca.gov/hq/research/researchreports/1966-1967/66-10.pdf

20. FILE NAME

66-10.pdf

THE APPLICATION of a NUCLEAR SOIL GAGE to CONSTRUCTION CONTROL



66-10

JANUARY 1966

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 426028-2

State of California
Department of Public Works
Division of Highways
Materials and Research Department

January 11, 1966

Lab. Auth. 426028 - 2

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is a report on:

THE APPLICATION OF A NUCLEAR SOIL GAGE

TO

CONSTRUCTION CONTROL

Study made by .... Foundation Section
Under general direction of .... Travis Smith
Work supervised by .... W. G. Weber
Report prepared by .... D. R. Howe

Very truly yours,

John L. Beaton
JOHN L. BEATON JWS
Materials and Research Engineer

Attach.
cc: LR Gillis
JF Jorgensen
AC Estep
J Obermuller
G Ebenhack
S Helwer
W Hegy
E Blomquist
B Walker
H Benedict
M Clemens

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ACKNOWLEDGMENTS

The contract upon which this study was conducted, was under the general supervision of the District 01 Construction Engineer and under the direct supervision of the Resident Engineer. Considerable credit for the successful application of the nuclear gages in this study is due to the efforts of district personnel and especially to Mr. H. W. "Hod" Benedict, Resident Engineer, and his two test operators, Mr. D. B. Grinsell and Mr. L. D. Addison.

This research study was financed by State of California, Division of Highways research funds under work order authorization No. 64-19U51H1. Operational liaison between the project and the Materials and Research Department was undertaken by Mr. R. E. Smith and Mr. B. L. Lister. The consultation services, concerning the statistical aspects of this study, were provided by Mr. R. O. Watkins.

The Application of a Nuclear Soil Gage in Construction Control

INTRODUCTION

The California Division of Highways has been active in the investigation of portable nuclear soil density and moisture gages since 1959. Several intensive laboratory and field studies have been undertaken by the Materials and Research Department and reported in detail (1) (2) (3) and (4).

While these studies have examined many facets of the operation of nuclear devices, including their experimental use on construction projects (2) (4), the gages had not yet been tried as the sole means of determining in-place density and moisture on a going contract. As a consequence very little, if any, information has been derived concerning the problems which might arise from the implementation of the devices by contract specification. The administrative aspects, creation of a practical test method and other factors such as the training of personnel, health safety, equipment durability, etc., could all affect the feasibility of nuclear gages for use in compaction control. It was therefore decided that the overall nuclear density program had come to a stage where a pilot study, using a nuclear soil gage for actual construction control, was indicated.

As a result of this decision, inquiries were made in several districts regarding a prospective project for this study. In making the selection it was necessary to consider factors such as project timing, type and scope of work, location, etc.

After considerable investigation, a large project was chosen in the Eureka Highway District on U.S. 101 near Garberville. This contract concerned the placement of approximately 615,000 cu. yds. of fill and considerable structure backfill, permeable material, base and subbase. The project proved to be ideally suited for the study in that a wide variety of conditions and materials were encountered.

It is the purpose of this report to examine the application of nuclear gages to specification control, on this contract, and analyze the data obtained from the field operation of the equipment.

CONCLUSIONS AND RECOMMENDATIONS

1. The use of nuclear soil gages in conjunction with the "Multiple Testing" concept provides a more comprehensive coverage of construction compaction than previous methods embodying the sand volume test.

2. The average relative compaction value, calculated from a series of nuclear tests obtained from an area having one soil type, provides a significant index to the degree of compaction attained in construction.

3. The use of the average relative compaction value in conjunction with the limitation on the proportion of failing tests within a given area (not more than one-third should fail), as a basis for accepting or rejecting a compacted quantity of soil, is realistic and is feasible for construction control.

4. It is recommended that wherever possible areas be subdivided into sections and a minimum of two random nuclear sites be required per section. In special cases (e.g., Structure Backfill) an area can be a section, in which instance a minimum of three nuclear sites should be required.

5. Training of construction personnel in the safe and effective use of nuclear soil gages is feasible.

METHOD OF OPERATION

The contract (028744) selected for this study, involved the realignment and widening, to a four lane facility, of road 01-Hum-101-PM 14.3/16.8. The project is situated in the rolling, forested, north coastal region of California about 60 miles south of Eureka. The location map, shown in Figure 1, illustrates the general layout of the project.

In order to establish the nuclear soil gage as the method of compaction control, on this contract, it was necessary to provide two important contractural items. First, a test method was written detailing the manner of nuclear density and moisture determinations and displaying the method of calculating percent relative compaction. This procedure is designated as Test Method No. Calif. T231-A and is shown in Appendix A of this report. The second item involved the writing of a specification which resulted in the following statement being placed in Section 10-1.11 of the contract special provisions:

> "Relative compaction of earthwork will be determined by experimental nuclear Test Method No. Calif. T 231 in lieu of Test Method No. Calif. 216. Copies of this experimental test method may be obtained at the Materials and Research Department, Division of Highways, Sacramento, California, and will be furnished on request."

Training of project personnel was undertaken in the spring of 1964. The resident engineer and two technicians were sent to Sacramento for a concentrated one week's course of instruction. The course included the basic concepts of nuclear physics, health safety, application of the test method and operation of nuclear equipment.

Upon conclusion of the training the project personnel returned to the district with the nuclear equipment. Construction control operations, on the project, were undertaken from June 1964 through October 1964 and again from May 1965 through July 1965.

The devices used in this program are backscatter type gages manufactured by the Nuclear-Chicago Co. The density gage is a Model P-22 and measures the Compton effect of radiation acting upon the soil from 3 millicuries of Cesium 137. The moisture instrument is a Model P-21 and measures the effect of neutron moderation by soil water, utilizing a 5 milligram source of Radium-Berylium.

In the initial phases of the project, the nuclear testing involved the undertaking of both density and moisture calibrations on the soils encountered, in accordance with Test Method No. Calif. 231-A. While the specification control aspects of the contract only required nuclear testing on "Earthwork", it was found desirable, for the purposes of the research study, to include structure backfill and structural section materials in the testing program. As a consequence it was necessary to perform calibration checks on four general classes of materials. These were embankment, structure backfill, aggregate base (AB) and aggregate subbase (AS).

In addition it was found, after construction started, that the embankment material was composed of two distinct soil types which required individual consideration in calibration operations. One soil type was a clayey excavation material, containing some rocks, and the other was a river bed silt.

Calibration and subsequent control testing was accomplished, in this study, by relating "count ratios" to density and moisture respectively. A count ratio is calculated for each nuclear soils test by dividing the test count by the standard count.* This ratio then becomes the test value which is correlated with density and moisture in the calibration and multiple testing operations. The use of count ratios, instead of test counts as was done in a previous study (4), tends to compensate for chance variation in the daily functioning of the electronic circuitry, source, etc., which might influence the test values determined for density and moisture.

In the planning stages for this study, it was proposed that evaluation of compaction would be undertaken on the "single test basis." That is, at each nuclear test location (or site), a sample would be obtained for the performance of the Impact Compaction test (see Test Method No. 216-F, Part II) and the relative compaction of the soil would be determined from the ratio of the nuclear in-place density to the maximum test density at that site. This is essentially the same practice as that traditionally employed with the Sand Volume test.

Before construction control operations could be undertaken however, a scheme embodying the so-called "Multiple Testing" concept was conceived. In this approach, a compacted area of roadbed or structure backfill, having the same soil type throughout, is chosen for a series of tests. Sites within this area are selected at random and in-place nuclear density and moisture tests performed at each location within the area. Relative compaction values are then calculated for each test density found, utilizing the maximum density obtained on the soil type from the Impact Compaction test. The <u>average</u> relative compaction, determined from the group of tests, is then used as the basis for determining whether the area passed or failed to meet the minimum specification limit for the material in question. It was this "Multiple Testing" concept which was actually used for compaction control from the outset of construction operations.

In the early stages of construction a sample of soil would be obtained, for the Impact Compaction test, from the site of the nuclear test nearest to the average nuclear density value, within the area in question. The maximum density thus obtained would then be used to compute the relative compactions from the individual nuclear tests within this area. However, later in construction, after considerable impact data had been accumulated, the average maximum density for the particular soil type under nuclear test was used to calculate relative compaction values.

*See Part B of Test Method T 231-A for procedure for determining standard counts.

ANALYSIS OF DATA

Calibration:

Several distinct soil types were encountered on this project which developed somewhat different calibration curves. While the embankment was composed mainly of a clayey material, a minor amount of river bed silt was used in the early stages of fill construction which demonstrated a different count ratio-density relationship from the clay. Comparison of the "clay" and "silt" curves can be made in Figures 2 and 3, respectively. In addition to the fact that the structure backfill, aggregate base (AB) and aggregate subbase (AS) came from the same materials source, calibration checks confirmed that all aggregates behaved in the same manner with respect to the density-count ratio relationship. As a result one calibration curve could be applied to these imported materials, without distinction, as shown in Figure 4. However, this curve differed somewhat from the two embankment soil classes. Direct comparison of the three curves may be made in Figure 5.

An indication of the differences in the physical characteristics of the three materials may be seen from the results of the impact compaction test. In Figure 6 the frequency distribution of impact tests by maximum dry density (in 4 p.c.f. groups) is illustrated. It is noted from this figure that the silt ranged from 118 to 129 p.c.f., the clay from 125 to 139 p.c.f. and the structure backfill, AB and AS group from 140 to 149 p.c.f.

The calibration "curves" used for the project were constructed assuming a linear correlation between count ratio and "sand volume" density. The straight lines were drawn through the plotted data at locations of estimated "best fit," (i.e., estimated without calculation) taking into consideration the experience with this type of correlation from previous 1962 studies (2) involving the same gage on soils of similar character. In general an attempt was made to maintain some degree of parallelism with the 1962 lines. These estimated best fit lines were used for construction control.

Comparison of these best fit lines with calculated* regression lines, shown as lightdashed lines, may be made in Figures 2 through 4. With the exception of the "clay" calibration chart (Fig. 2), it appears that the method of estimation agrees reasonably well with the statistical determinations and for practical purposes is satisfactory. In the case of Fig. 2, it appears that the point on the extreme left exerted undue influence upon the calculation of the regression line. As a consequence it is felt that the "best fit" line represents a more realistic and better engineered relationship. There is an advantage in the use of careful estimation, based on experience, in that useful calibration curves can be developed, from limited data for immediate application to construction control, without waiting for the complete data to perform statistical calculations.

*By method of least squares.

The precision of the calibration data, calculated in terms of the standard deviation from the estimated best fit line, is illustrated in Table I for each of the soil types. Also, for comparison, the standard deviation from the calculated regression line is shown in the table. It is noted that the standard deviation from the best fit lines ranges from 3 to 6 p.c.f., which is well within the findings from previous studies (3) (4).

TABLE I

Standard Deviation of Density Calibration Tests

		Standard Deviation (p.c.f.)	
Soil Type	No. of Tests	Best Fit Line	Regression Line
Silt	3	3 p.c.f.	3 p.c.f.
Clay	8	6 p.c.f.	6 p.c.f.
Struct.B.F.	8	4 p.c.f.	2 p.c.f.
AB & AS			

Figure 7 illustrates the moisture calibration data obtained from the project. This scatter diagram was plotted on the basis of count ratio versus "oven dry" moisture content (in lbs. of water per cubic foot of soil) of the soil samples subjected to the respective moisture tests. Assuming linear correlation between these two variables, both "best fit" and a straight regression line are shown in Figure 7. However, only the best fit curve was used for field moisture determination. The standard deviation of the data from either curve is 1 lb. per cu. ft., which agrees with the ± 2 p.c.f., within 90% confidence limits found in previous studies (2) involving the nuclear moisture tests.

In general there was not a constant need for soil moisture content data on this project since most of the relative compaction determinations were made on the "wet density" basis. As a consequence only occasional tests were made for informational purposes at the option of the Resident Engineer. However in a minority of cases, where a "rock correction" was applied to the impact compaction test and the maximum density was necessarily determined in the dry condition, the nuclear wet density was converted to dry density with a nuclear moisture determination obtained at the same site. In these instances the relative compactions would be calculated on the "dry density" basis.

Aside from the obvious time savings involved, the desirability of using the "wet density" basis, in preference to dry density (except where rock corrections in the impact test are required) for calculating relative compaction, is primarily a matter involving the statistical accuracy of the relative compaction determination. When dry density is used, the impact test densities must be converted to dry density with the oven dry moisture content and likewise the nuclear density must be adjusted with a nuclear moisture determination. Both of these moisture tests have normal chance variations which increase the overall chance variation in relative compaction when the dry method is used. Experience has shown that the standard deviation of oven dry moistures is approximately 1 p.c.f. and it has already been noted that the standard deviation of the nuclear moisture test in this study is 1 p.c.f. On the other hand both the impact and nuclear density tests can be determined directly in terms of wet density, thus obviating the variations caused by moisture determinations.

Construction Control Testing:

The relative compaction (RC) data, derived from the nuclear construction control testing on the project, is shown in Tables II and III for embankment and structure backfill (including AB and AS), respectively. The tables are arranged to display the test values at the individual sites* as well as the averages for the various areas** tested. Those area averages, which do not meet the relative compaction specification requirements for the particular material being tested, are underlined to indicate that they are "failing" or unacceptable areas.

Of particular interest, is the manner in which this data is distributed over a range of relative compaction values. Figures 8 and 9 are frequency distribution (histogram) charts, constructed from the data in Tables II and III respectively, for test site values. Tests from passing areas are shown as solid bars while the values from failing areas are indicated in crosshatch. Figures 10 and 11 are similar plots of area averages.

It is noted from Figure 8 that the tests from the passing embankment areas (solid bars only) range from a low of 80% RC to a high of 106% RC. The average for this distribution is 95.2% and the standard deviation is 4.2%. These findings agree favorably with those of Jorgensen and Watkins (5) in their study involving the application of the sand volume test to several projects. It is felt that the above statistical data indicates that overall good compaction was obtained on the project.

While the majority of tests from the passing areas were at or above the minimum 90% RC specification for the embankment, it can also be seen in Figure 8 that there is a small group of substandard RC values scattered through these areas. These tests represent about 9% of the total tests from the passing areas. This conforms well with the findings of the AASHO road test (6), where 8.7% of the tests fell below the specification limit. Since it is generally agreed that the AASHO Test Track was constructed with the greatest possible care, this comparison appears to provide further evidence of good construction on the District 01 project.

*A "site" is defined as a single location on the roadbed where test measurements are performed.
**An "area" is a zone on the roadbed embodying a group of "sites."

In the case of the structure backfill, AB and AS the trend of the tests show a similar pattern, as illustrated in Figure 9. The passing areas indicate a range of 88% to 108% RC, an average of 99.8% and a standard deviation of 3.4%. There are about 8% of the tests from the passing areas which fall below the minimum specification of 95% RC.

It should be noted, in the above statistical analysis, that the tests from the failing areas (shown as crosshatched bars in Figures 8 and 9) were not included in the calculations. The primary reason is that the failing areas were reworked by the contractor and retested until the area averages met the specification limit. As a consequence these failing values no longer relate to the finished product and the acceptable retest values are included with the original tests for the passing areas. The purpose of showing the failing area tests, in the figures, was merely to provide an impression of the proportion and distribution of these tests encountered during construction operations.

The distribution charts for the area averages of both types of material are shown in Figures 10 and 11. It is to be expected, in these charts, that the passing area will only extend from the relative compaction specification limit upward, since the failed areas are normally reworked and retested until they too become passing areas. However, it should be pointed out that this does not present an entirely true representation of the probable final state of compaction. Besides the statistical effect of increasing the probabilities of obtaining passing samples through retesting, as demonstrated by Jorgensen and Watkins (5), the limitations of sampling tends to result in a distorted impression of the true "universe" conditions. The normal or bell shaped curves, superimposed on the respective charts, indicate the most probable distribution for all possible test areas (universe distribution) for each material. It can be seen that a portion of each distribution curve extends somewhat below 90% and 95% RC, indicating that some material may still be below the specification limit.

It is felt that there are two possible ways of modifying the test procedure, on multiple testing, which would tend to minimize the chance of including substandard compaction in the final product. First there should be some limitation placed upon the number of failing tests which can be allowed within an area having a passing average and still have the area acceptable. This will be analysed and discussed in following paragraphs. Secondly, there should be some measure of control on the spacing and minimum number of test sites within an area. The need for control of spacing, without seriously restricting the randomness of sampling, was indicated by data displayed in a previous field study (4). In the present study there were no restrictions placed upon the minimum number of tests within an area. As a consequence there were some embankment areas which contained only one, two, three or four tests (see Table II). Likewise in structure backfill AB and AS there were several instances where only one or two tests were performed (see Table III). It appears that dividing an area into several sections and requiring a minimum number of random test sites within each section, offers a possible solution to the problem. Where the volume of structure backfill is small, the minimum number of tests might be reduced somewhat. The method of subdividing major production units into sub-groups (or sections) is common practice, for statistical quality control, in industry today.

While the number and magnitude of failing tests has a direct influence upon the area average it is possible, in marginal cases, to have considerable evidence of failing tests and still have an acceptable average. A review of Tables II and III will reveal a number of occurrences of this nature. This problem was observed and discussed briefly in the previous field study (4) and has been recognized by other investigators (7). The question is, where does one "draw the line" in tolerating individual sub-standard relative compaction values?

In order to more clearly illustrate the situation, in this regard, relative compaction data is plotted in Figures 12 and 13 for only those passing areas containing individual tests which fail to meet the minimum specification requirement. Other passing areas in which all test values are satisfactory, are not considered in this case. Individual test points and area averages are plotted against relative compaction in the ordinate. In the abscissa, the areas are grouped in proportion of passing to failing tests* with the "passing" ratio diminishing from left to right (e.g. 5/6:1/6, 4/5:1/5, etc.). Within the groups, the areas are generally arranged to show increasingly unsatisfactory test values to the right.

It is noted, in Figures 12 and 13, that there is quite a broad combination of high and low test values which can result in passing area averages. However it appears that the chances of obtaining a passing average diminishes rapidly when the proportion of individual failing tests exceeds 1/3. Out of a total of 52 passing areas, on the embankment, only 4 passing areas contained more than 1/3 of the tests in the failing category. Thus it appears to be a rather unusual circumstance when an area, with more than 1/3 of the tests below the specification limit, has a passing average and that rationally these areas could be considered as failing.

Looking at the problem from another viewpoint, Figures 14 and 15 are plotted in a similar manner, to show the tests in areas whose averages do not meet the minimum specification requirements. For embankment (Fig. 14) it can be seen that only one group has 1/3 failing and in this instance the average is just one point below 90% RC. When the proportion of failing tests increases to 2/3, 3/4 and all failing, the averages drop off quite rapidly. A similar situation exists in the case of structure backfill, AB and AS (Fig. 15) where it is noted that there are no failing areas tested on the project having less than 1/2 of the tests failing and the averages diminish fast at progressively higher proportions of failing tests. The fact that areas, failing by virtue of sub-specification averages, normally contain a preponderance of failing tests, provides further evidence to support the contention that areas containing more than 1/3 failing tests should be automatically classed as failed areas, even though the area average occasionally meets the specification requirement.

*With arbitrary graph spacing.

DISCUSSION OF TEST OPERATIONS

In the introduction to this report mention was made to the effect that nuclear in-place density and moisture tests had not yet been tried as the sole means of specification control of this important construction item. As a result this study was inaugurated as the first real test of the nuclear method for this purpose. Many other trials have been made, utilizing nuclear devices on construction projects, but always with the option that the "tried and true" methods could be easily substituted in the event problems occurred, without altering the original contractural agreement.

It has already been seen in the analysis of data, that this pioneering experiment has produced valuable data leading to the development of a realistic and rational test method. However, in order to gain a more complete insight into the application of the test under the pressure of construction operations, it is necessary to examine some of the practical features involved in the implementation of the nuclear control method. These items will be discussed in the following paragraphs.

One of the problems encountered on the project involved difficult seating conditions for the probe when testing embankment material. While the matrix of this soil is primarily composed of clay (except where a minor amount of river bed silt was used), there is also a considerable amount of shale and sandstone rock included in the material. Scraping of the ground surface often leaves the rocks protruding and causes an air gap under the probe which in turn affects the nuclear counts. Also the rocks had a tendency to "pop out" leaving pockets in the surface requiring the use of "natural fines" to fill the voids. Several instances are noted in the records that retests were necessary due to seating difficulties (See Table II). However, as the job progressed, the test operators developed techniques which tended to minimize the difficulties. In any event usable nuclear data was obtained in many instances where the soil was too rocky to perform the sand volume test.

Recent studies by the Materials and Research Department indicate that the transmission type nuclear gage tends to overcome the difficulties arising from rocky soils. This device tests a larger volume of soil and is not nearly so sensitive to surface condition. The problem of introducing the source (or pickup tube) below ground in a rod has been largely overcome by the use of a commerically available drill which forms a neat hole through rocky or fine grain materials alike.

The health-safety aspects of nuclear testing did not present any difficulties on this project. There was no apprehension indicated at any time by either the State employees, the contractor or the general public. Each operator and the resident engineer were equipped with film badges and dosimeters to monitor exposure. The average weekly dosage received by these people ranged from 2 to 3 milliroentgens equivalent man (mrem). Background radiation, normally received by all human beings is 1 to 2 mrem per week. The highest dosage received by the test operators in any one week was 9 and 12 mrem, respectively. This is well below a 50 mrem per week limit normally observed by this department or the 100 mrem maximum allowable specified by the California State Department of Public Health.

There is no doubt that nuclear testing brings with it somewhat increased administrative effort. On this project the resident engineer was responsible for the maintenance of weekly health safety records, physical examinations, considerations of nuclear source storage and transport. These items were effectively taken care of without any increase in personnel. Training along with maintenance and repair of nuclear equipment was handled through headquarters laboratory.

Operation of the nuclear equipment, in this study, was relatively trouble free. Early in the program the standard count was quite erratic as shown in Figure 16. While this did not appreciably affect the accuracy of the test measurements, since the count ratio method was used, it was indicative that something was not functioning properly in the electronic circuitry. Investigation revealed that the pickup tube was not sufficiently stable. After replacement of this detector, the standard counts resume their normally expected fluctuations. While a few minor adjustments of the gages were necessary, which did not result in any "down time", there were no further major problems experienced with equipment for the balance of the study.

In general, it appears that the nuclear method, in combination with the multiple testing concept, provides a very extensive coverage of compaction operations. There were 528 individual nuclear tests performed on the project in 72 days of testing, which averages a little over 7 tests per day. On a peak day (8-13-64), 16 tests were performed. While the above represents considerable testing, it does not demonstrate the maximum capabilities of the nuclear method, since the rate of testing is largely governed by the speed of the contractor's operations and the availability of test operators from other testing duties. Experience on this project indicates that 4 to 5 nuclear tests could be performed in one hour. This is in contrast to the sand volume test, where experience on this project indicates that 1 to 2 tests per hour is normal. Another asset of the nuclear method, which extends coverage, is that the in-place density can now be determined on many coarse granular materials which cannot be tested by the sand volume method.

In conclusion, this study has provided the basis for developing an effective and rational nuclear test method for future application to construction control. The nature of the compaction revealed by the nuclear tests on this project is very realistic, as evidenced by the pattern of the results shown in the frequency distribution diagrams. The resident engineer is very satisfied with the quality of testing and has indicated that he is desirous of utilizing the nuclear method on another project.

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TABLE II

Summary of Construction Control Data for Embankment Material

Note: Average values which fail to meet the 90% Min. R. C. spec. limit are underlined

Date	Test No.	RELATIVE COMPACTION, % 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	REMARKS
7-2-64	19	94	80	94	87	94	92										90	
7-3	20	91	91	91	92	85	91										90	
7-6	21	91	90	94	90	86	85										89	Silt
7-7	22	91	95	88	93												92	
7-8	23	95	93	100	98	95	94										96	
7-9	24	93	89	93	99	99	96										95	
7-10	25	97	95	101	101	100	99										99	
7-11	26	95	97	99	99	101	92										97	
7-13	27	69	66	88													74	Silt
7-14	28	101	103	94	105	99											100	Retest of 27
7-16	29	95	75	61	78												77	
7-18	31	97	95	96													96	
7-21	33	84	96														90	
7-23	35	99	101	96	100	98	98	98	98								99	Silt
7-27	36	97	99	94	97	98	97	97									97	
7-28	37	96	96	91	94	96	92										94	
8-3	43	87	87	97	97	94	99										94	
8-4	46	98	98	98	97	97	98										98	
8-5	48	91	91	88	84	93	95										90	
8-7	49	96	94	100	100	97	101										98	
8-7	50	94	97	97	95	95											96	
8-10	51	97	101	94	96	101	101										98	
8-10	52	87	79	90	91	88	86										87	Seating difficult
8-11	53	89	89	92	95	88	89										90	" "
8-11	54	88	95	89	97	86	96										92	" "
8-12	55	100	95	91	87	91	95										93	
8-12	56	92	94	90	92	89	91										91	Retest of 52, 53 & 54 (Not reworked)
8-13-64	57	97	97	99	97	93	92	93	92	92	92						94	

TABLE II (contd)

Summary of Construction Control Data for Embankment Material

Note: Average values which fail to meet the 90% Min. R. C. spec. limit are underlined

Date	Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	REMARKS
		RELATIVE COMPACTION, %																
8-13-64	58	91	92	96	93	95	94										94	
8-14	59	92	95	93	99	99	94	97									96	
8-14	60	88	85	87	93	94	92										90	
8-19	64	97	95	97	95	92	95										95	
8-19	65	80	81	88	87	87											$\underline{85}$	
8-20	66	96	96	91	95	96	91	97	99	91	94	96	95	101	102	95	96	Retest of 65
8-21	67	95	92	92	91	96	90										93	
8-26	73	100	100	96	97	97	97	97									98	
8-31	85	99	96	101													99	
9-3	87	88	92	92	92	92											91	
9-5	88	101	98	99	101	100	100										100	
9-5	89	90	93	93	91	96	94										93	
9-11	90	98	95														97	
9-11	91	98	95	97													97	
9-15	94	95	91	91	93	91	90										92	
9-16	95	91	94	90	91	89	92										91	
9-18	96	94	98	101	100	100	98	96	95								98	
9-19	101	100	100														100	
9-26	106	101	102	101													101	
9-26	108	86	92	88													$\underline{88}$	
9-30	113-A	92															92	Retest of 108
10-15	112	105	100	104	99	104											102	
10-20	113	98	93	100	100												98	
10-21-64	115	106	100	103	100	99	101	100	103								102	
5-14-65	120	92	92	86	90	88	92										90	
5-18	121	99	100	98	100	95	100										99	
6-8	123	98	96	96	100	98	105										99	
6-18	124	93	96	96	96	95	93										95	
6-18	125	97	98	96	98	95	97										97	
6-22-65	126	95	97	94	96	97	97										96	

TABLE III

Summary of Construction Control Data for Structure Backfill

Note: Average values which fail to meet the 95% min. R. C. spec. limit are underlined

Date	Test No.	RELATIVE COMPACTION, % 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	REMARKS
7-17-64	30	77	83	83	80												81	Str. Bkfl.
7-20	32	74	74	74													74	" "
7-23	34	82	82	74	89	73											80	" "
7-29	38	100	103	101	103	101	103										102	AB
7-30	39	99	97	93	86	96	93										94	Str. Bkfl.
7-30	40	103	99	104	101	101	101										102	AB
7-30	41	94															94	Str. Bkfl.
8-1	42	98	98	99													98	" "
8-3	44	95	93	90													93	Retest but orig. not recorded
8-4	45	92	97	100													96	Str. Bkfl.
8-5	47	94	95	95	95	92	96										95	" "
8-17	61	87	83	88	87	85	88										86	" "
8-17	62	95	94	97	97	99	94										96	" "
8-18	63	89	94	93	97	96											94	" "
8-22	68	100	102	88	96	97	100										97	" "
8-24	69	99	100	99	97	99	98										99	" "
8-25	70	95	96	98	97	95	94										96	" "
8-25	71	95	91	105	103	103	103										100	" "
8-26	72	93	105	106	105	97	105	104									102	" "
8-27	74	101	103	104	104	101	103										103	" "
8-27	75	105	105	99	103	99	104										103	" "
8-27	76	72	85	75	80	78											78	" "
8-28	77	74	78	86	98	96	98										88	" "
8-29	78	99	100	99	102	101	99	99	101								100	" "
8-29	79	95	94	91	100	96	97										96	Retest of 76 & 77
8-31	83	99	101	100													100	Retest of 41
8-31	84	100	101														100	Retest of 61
9-1	80	91	98	94													94	AS
9-1-64	81	101	101	99													101	AS

TABLE III (contd)

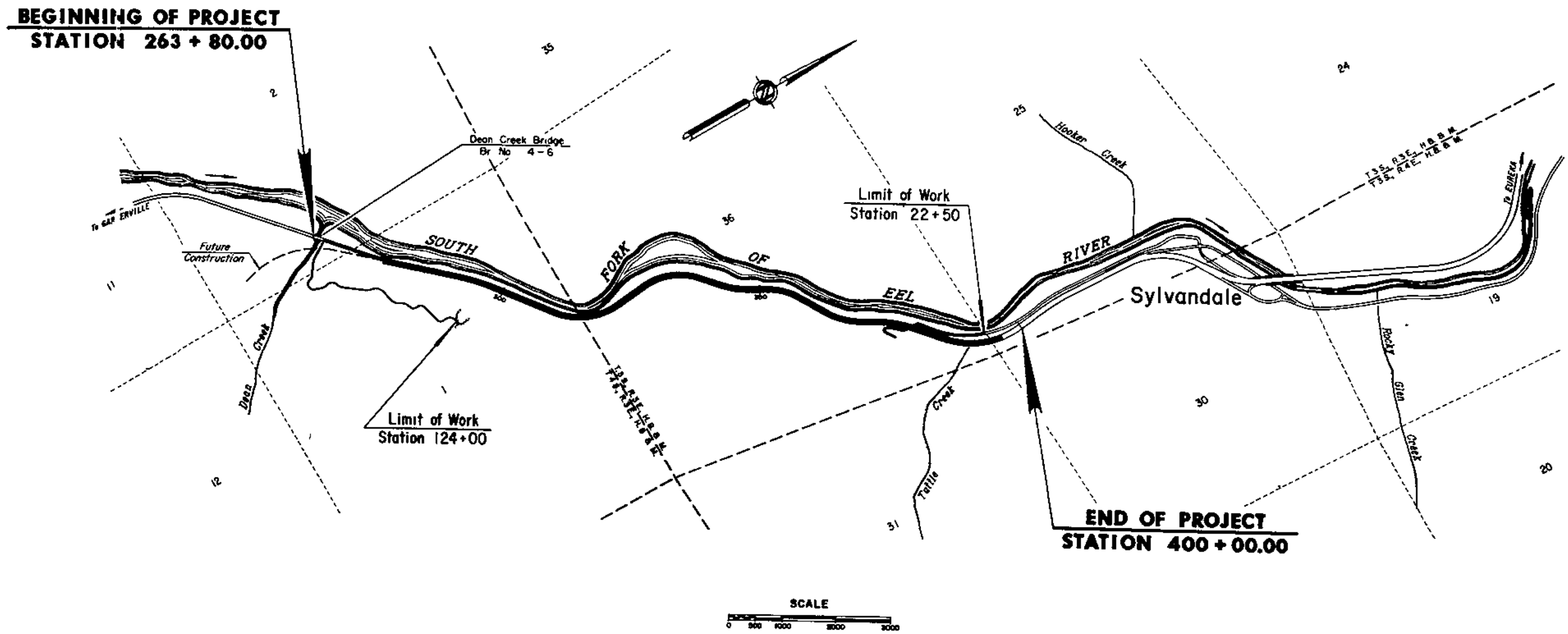
Summary of Construction Control Data for Structure Backfill

Note: Average values which fail to meet tne 95% min. R. C. spec. limit are underlined

Date	Test No.	RELATIVE COMPACTION, % 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	REMARKS
9-1	82	98	98	98	97												98	AS Retest of 80
9-3	86	100	100	102	105	104											102	Str. Bkfl.
9-11	92	103	104														103	Str. Bkfl.
9-14	93	101	105	103													103	AS
9-18	97	98	97	99													98	AS
9-19	100	103	101	104	99	102	102	99	102	95	100						101	AS
9-21	99	101	104	107													104	AS
9-23	102	101	100	100	101	99	98	98	96	96	98	101					99	AS
9-23	107	106	103	97													102	AS
9-26	105	97	98	97	101												98	AS
9-30	110	106															106	AS
10-20	114	99	96	99	99												98	AB
10-23-64	117	99	97	99	99	100	100										99	AS
5-11-65	119	94	98	101	93												97	Str. Bkfl.
6-8	122	93	87	84													88	Str. Bkfl.
7-2	127	99	101	103	102	101	100										101	AS
7-7-65	128	103	101	108	106	99	101										103	AS

In Humboldt County
between Dean Creek and 3.4 miles south of Phillipsville

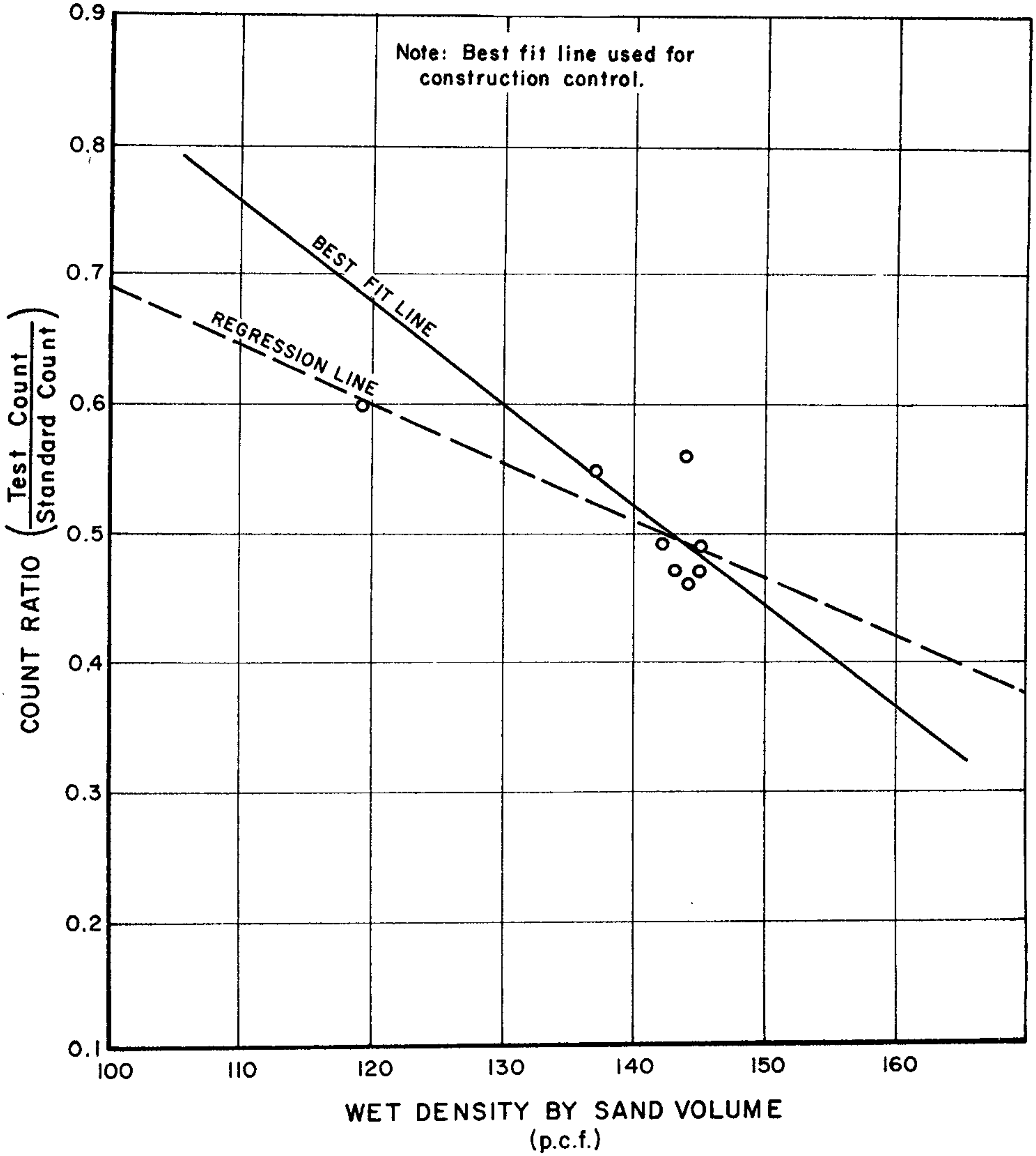
FREEWAY
By resolution of the California Highway Commission on March 21, 1956)



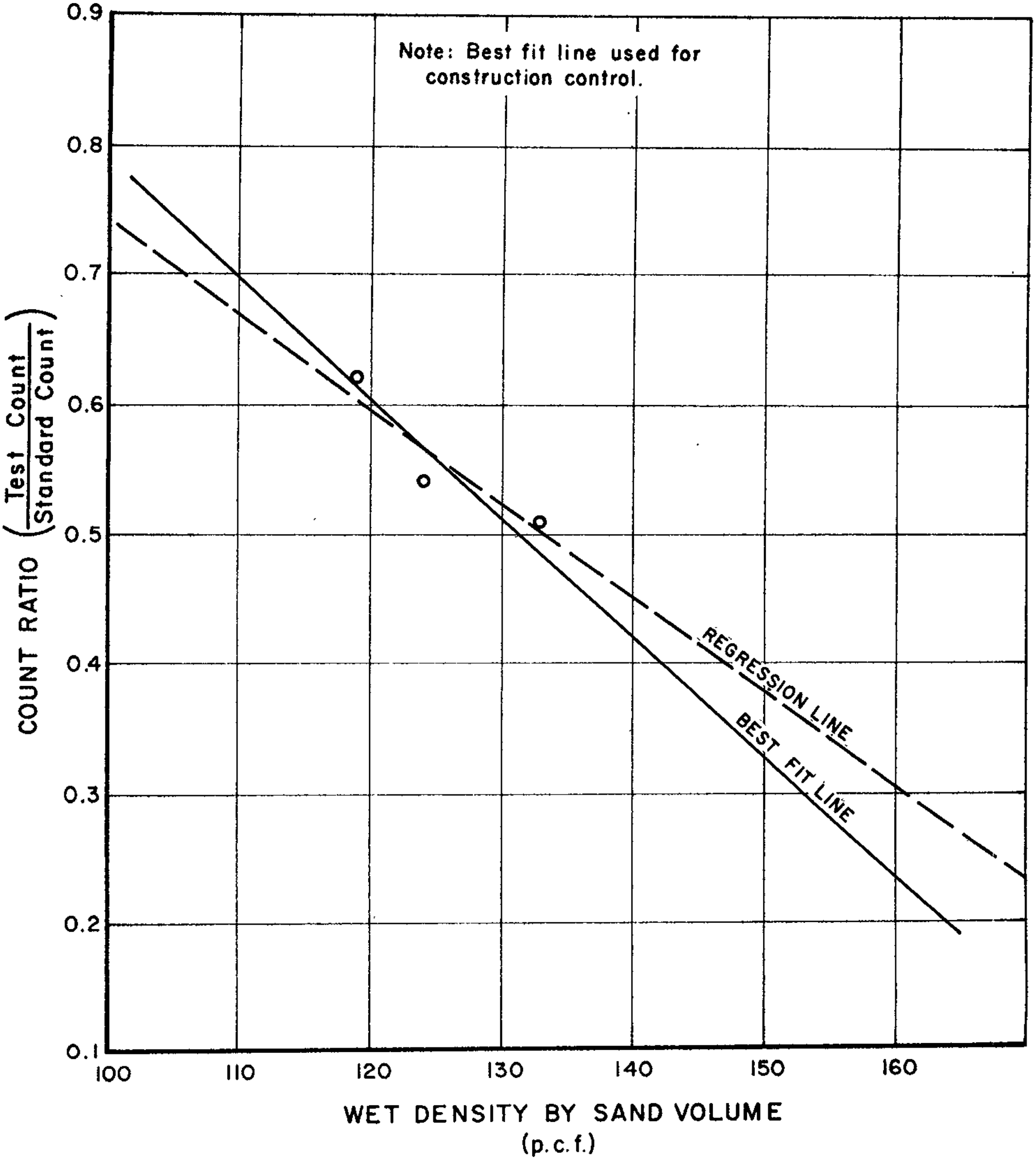
Length of Project: 13,620.00 Feet = 2.58 Miles

FIGURE 1

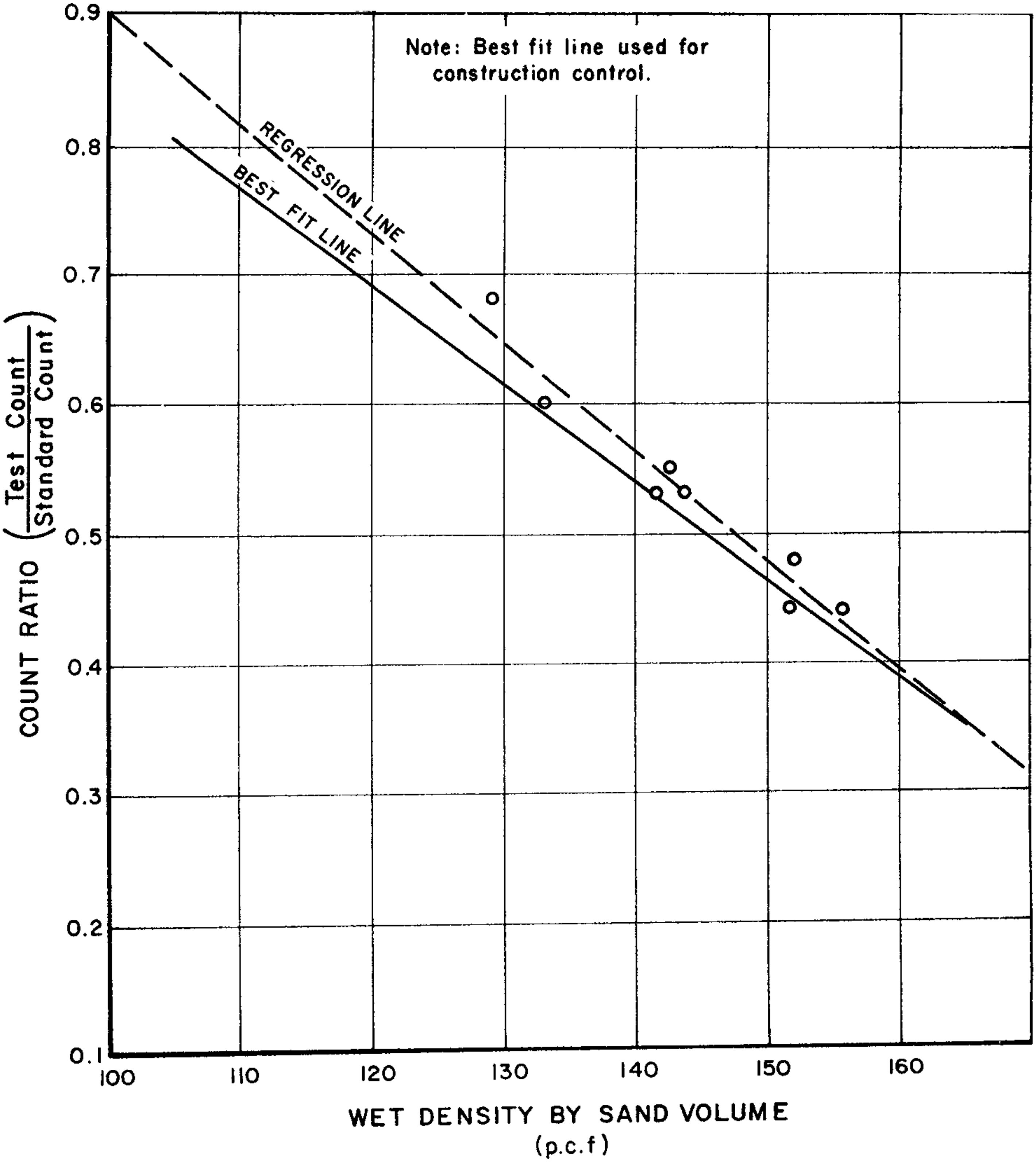
DENSITY CALIBRATION CURVE
01 - Hum - 101 PM 14.3/16.8
CLAY



DENSITY CALIBRATION CURVE
01 - Hum - 101 PM 14.3/16.8
SILT

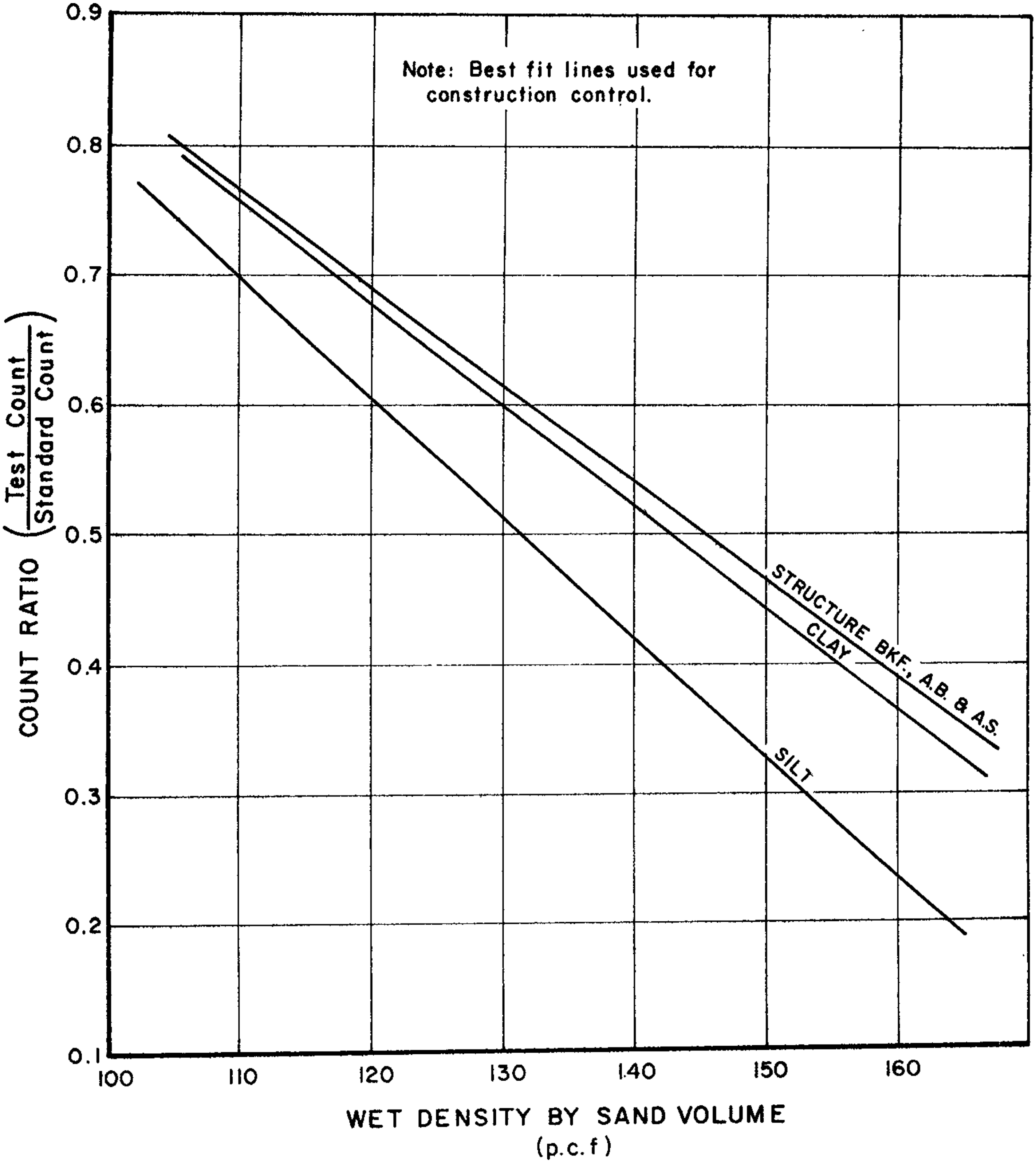


DENSITY CALIBRATION CURVE
01 - Hum - 101 PM 14.3/16.8
STRUCTURE BKF., A.B. & A.S.

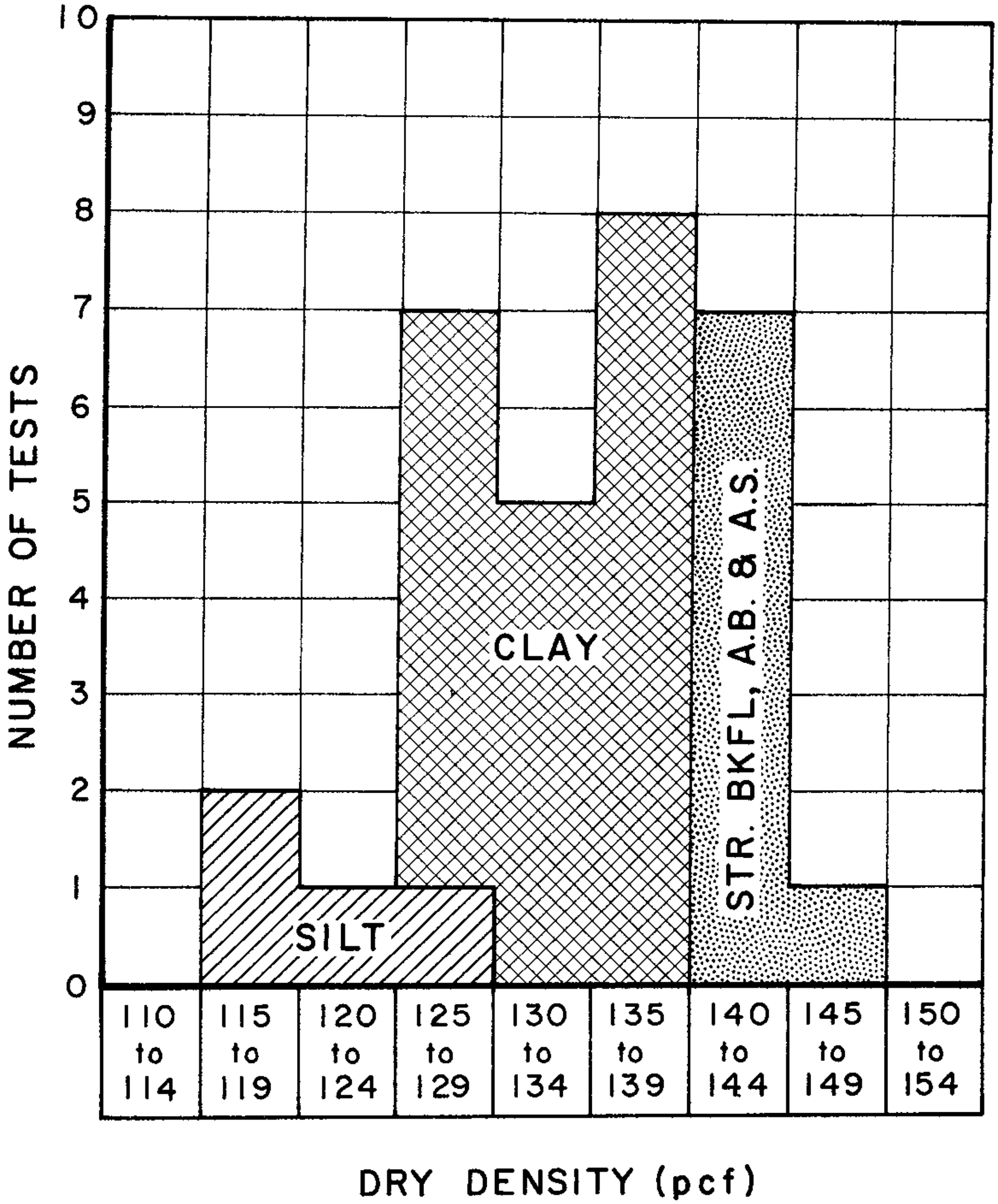


SUMMARY OF CALIBRATION PLOTS

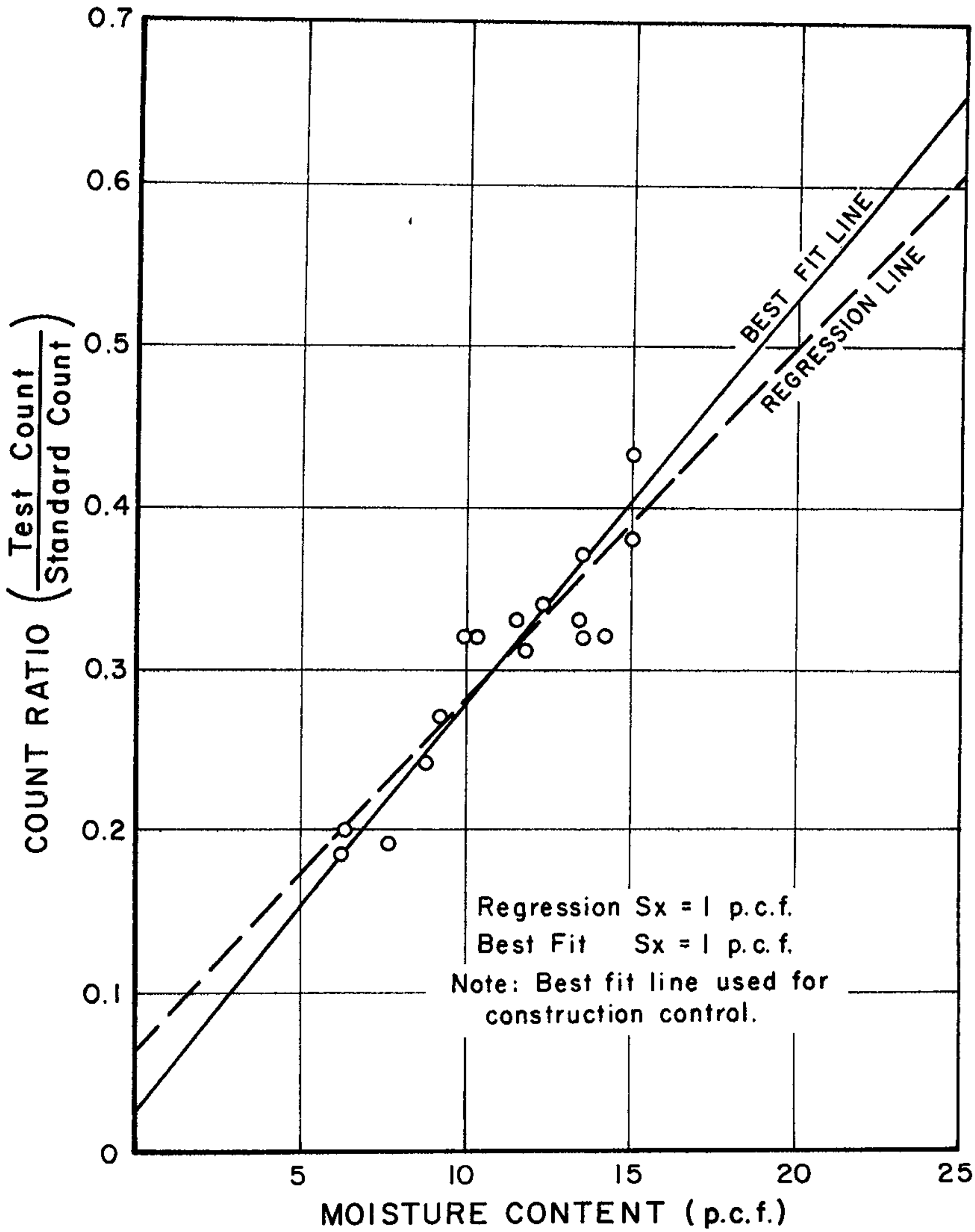
BEST FIT LINES



FREQUENCY DISTRIBUTION OF IMPACT COMPACTION MAXIMUM DENSITIES



MOISTURE CALIBRATION



FREQUENCY DISTRIBUTION OF RELATIVE COMPACTIONS AT INDIVIDUAL TEST SITES

EMBANKMENT

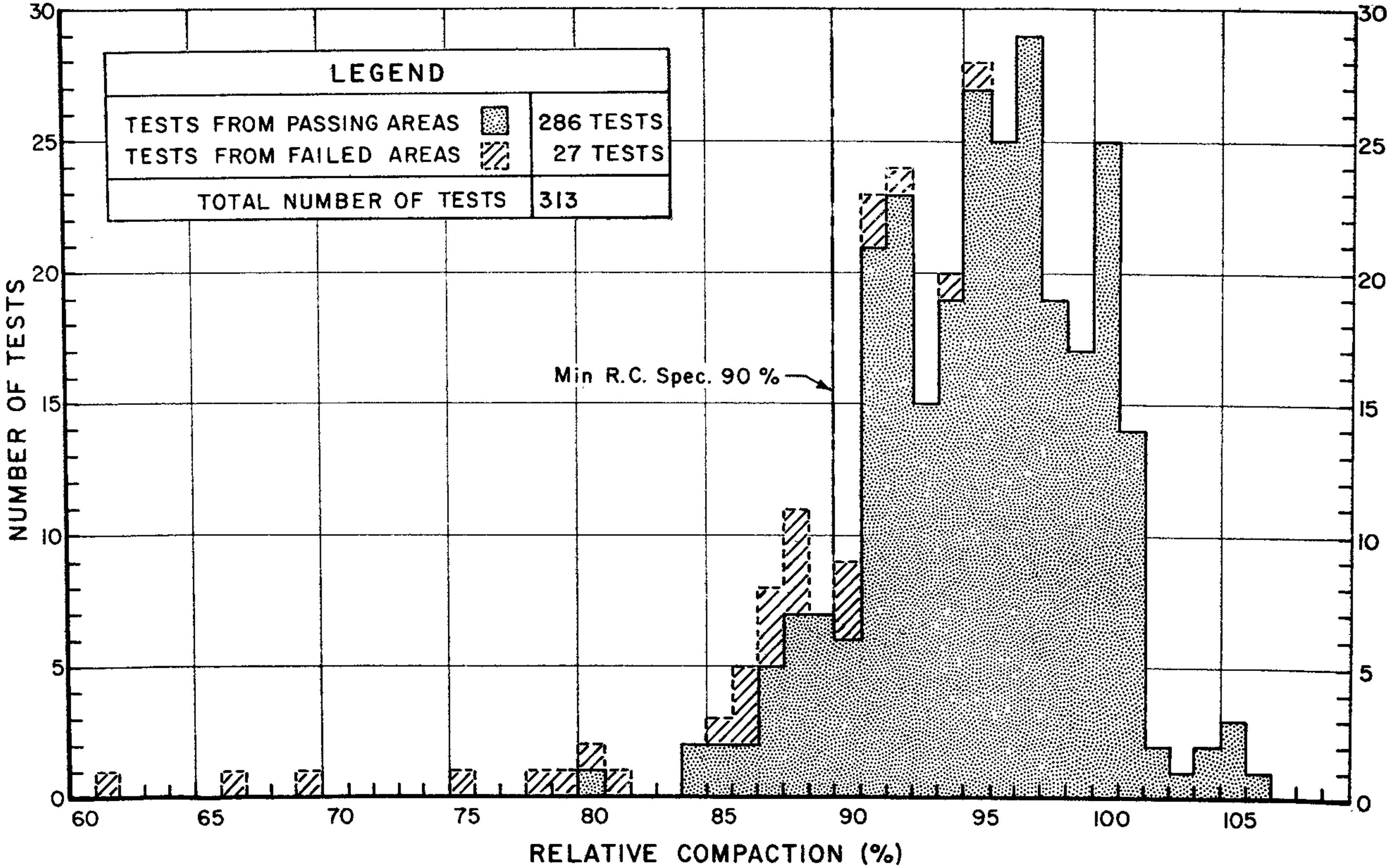
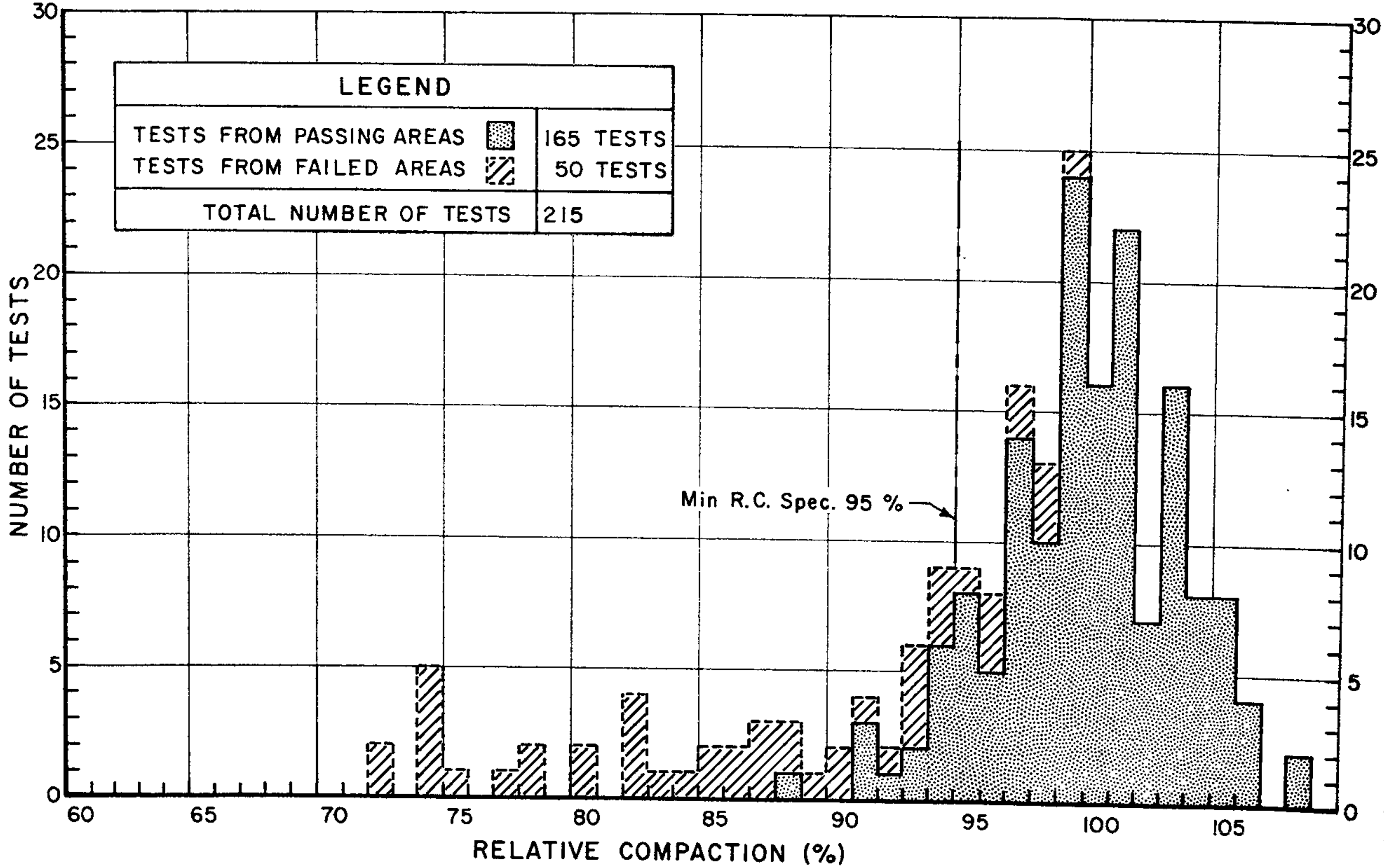


FIGURE 8

FIGURE 9

FREQUENCY DISTRIBUTION OF RELATIVE COMPACTIONS AT INDIVIDUAL TEST SITES

STRUCTURE BACKFILL, A.B. & A.S.



FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR TEST AREAS

EMBANKMENT

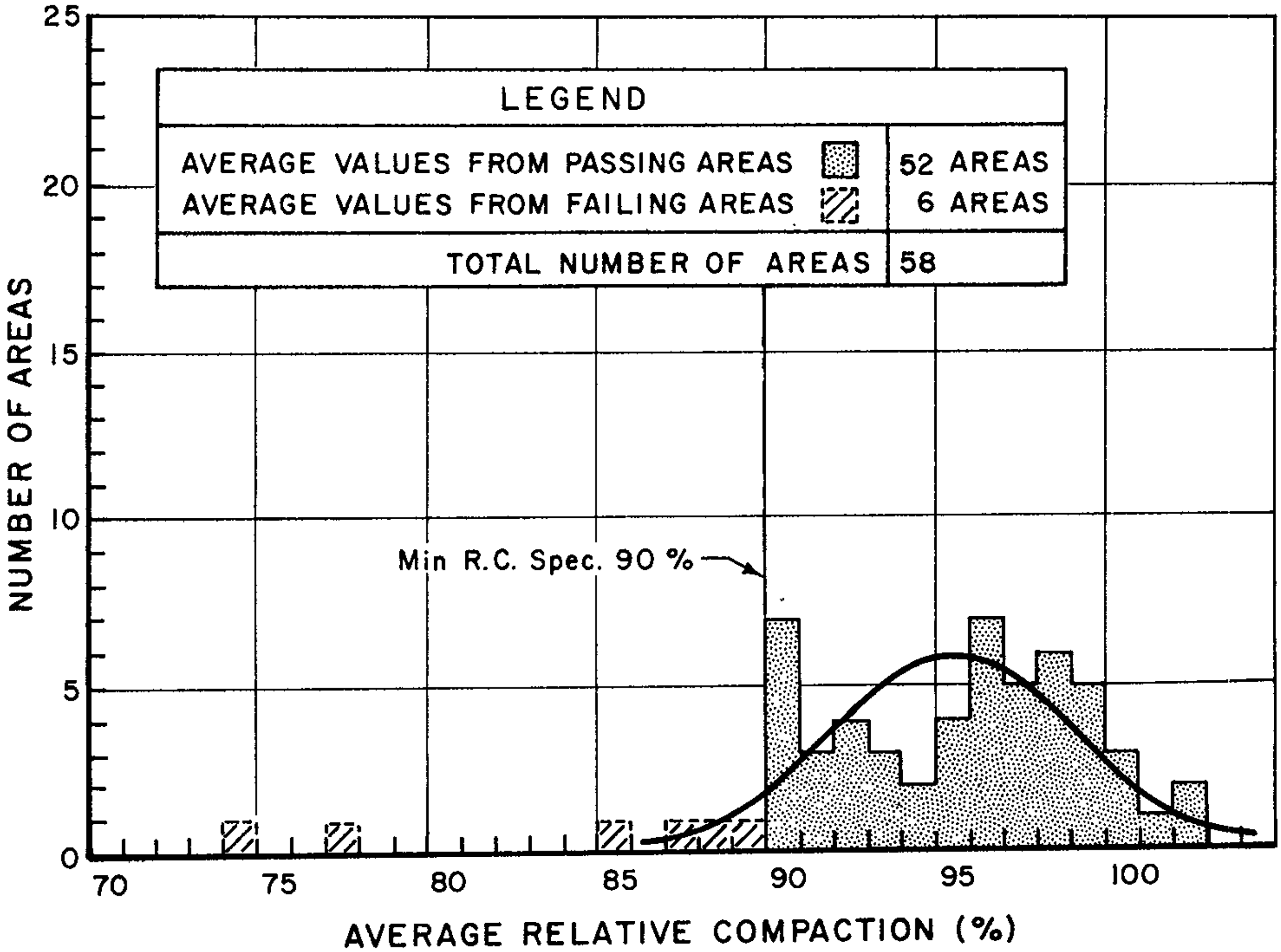
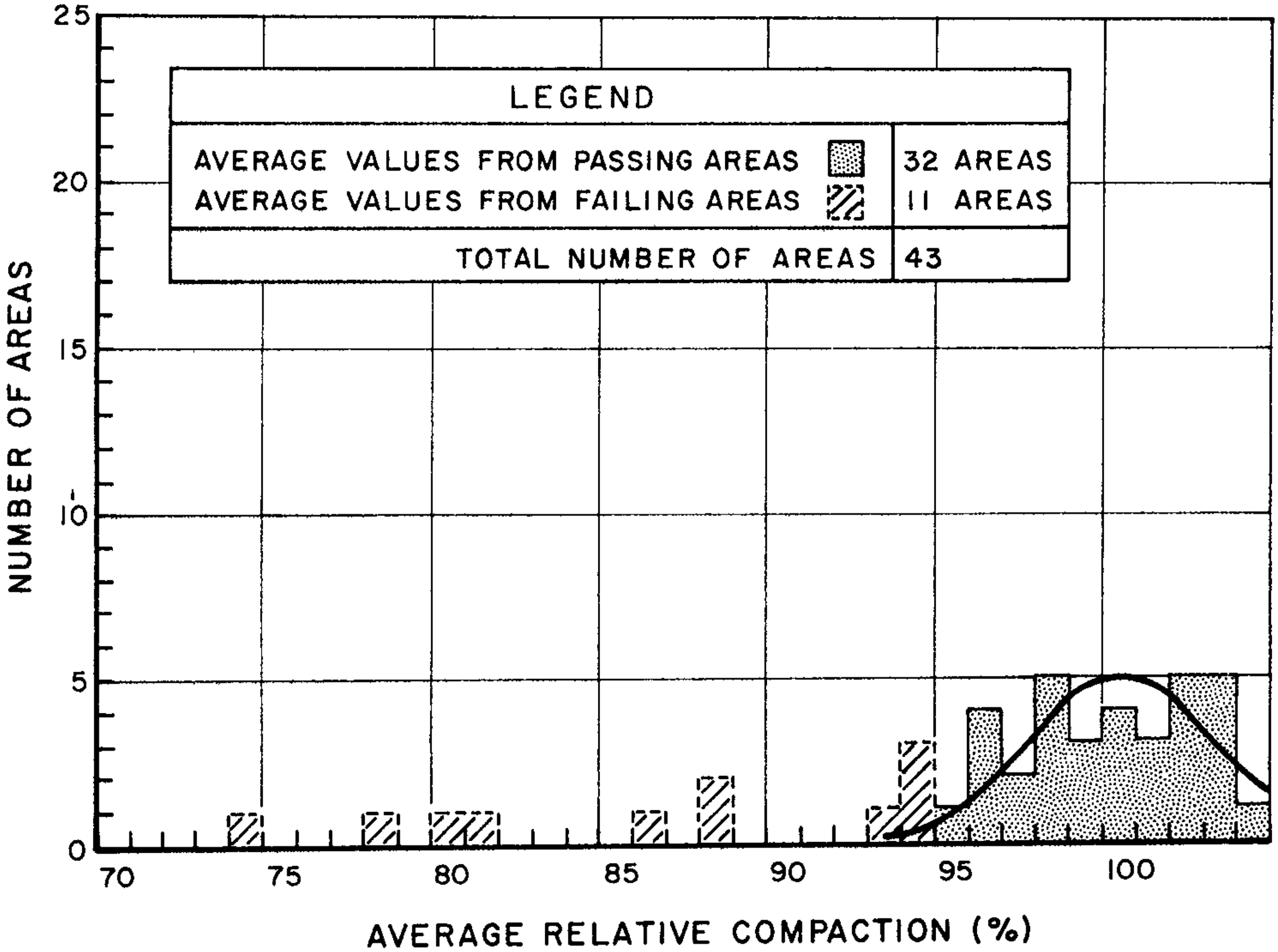


FIGURE 11

FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR TEST AREAS

STRUCTURE BACKFILL, A.B. & A.S.



EMBANKMENT

AREAS WHOSE AVERAGES MEET 90% MIN R.C. BUT CONTAIN INDIVIDUAL TESTS WHICH FAIL

GROUPED IN PROPORTION OF PASSING TO FAILING VALUES

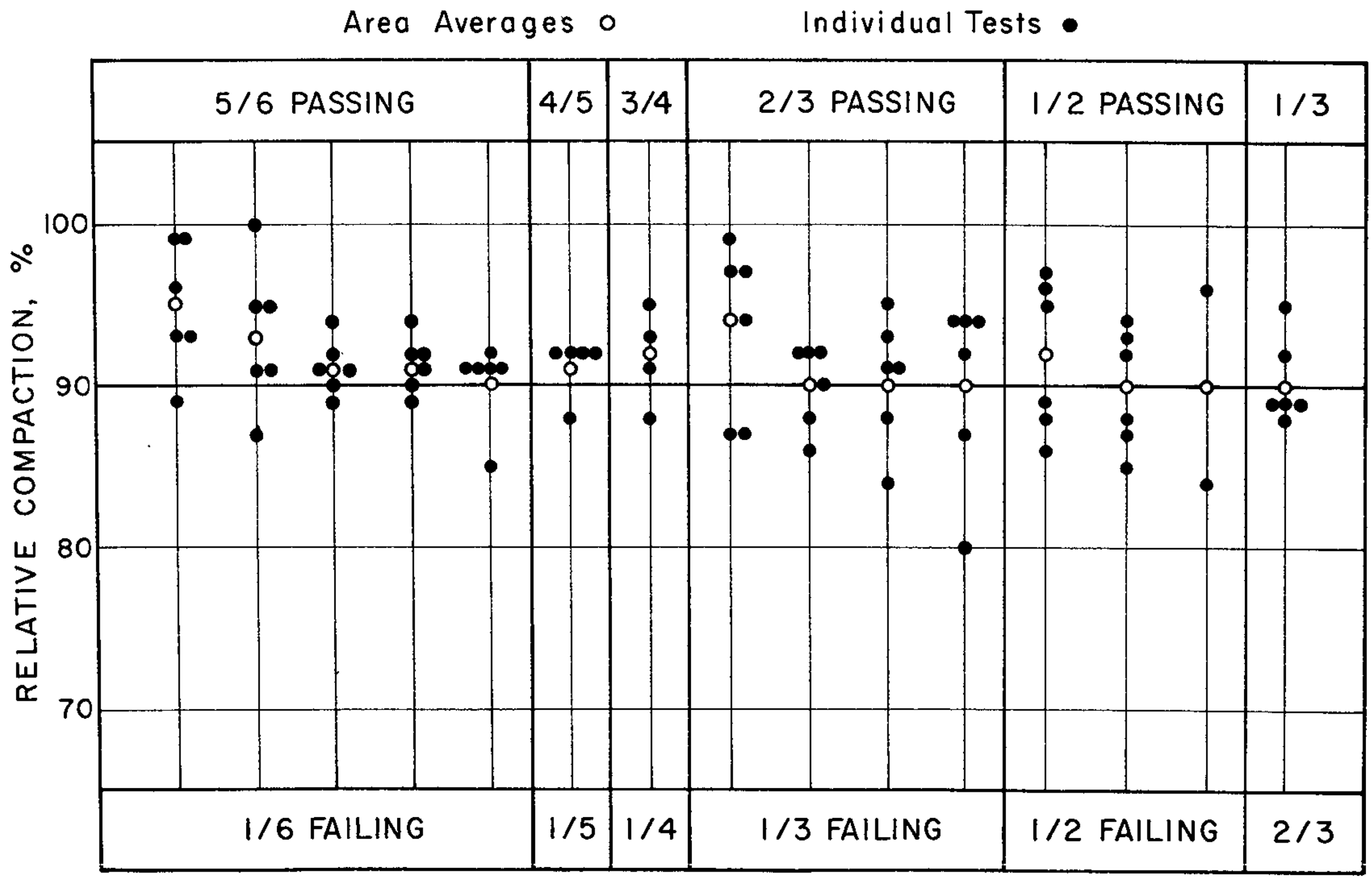


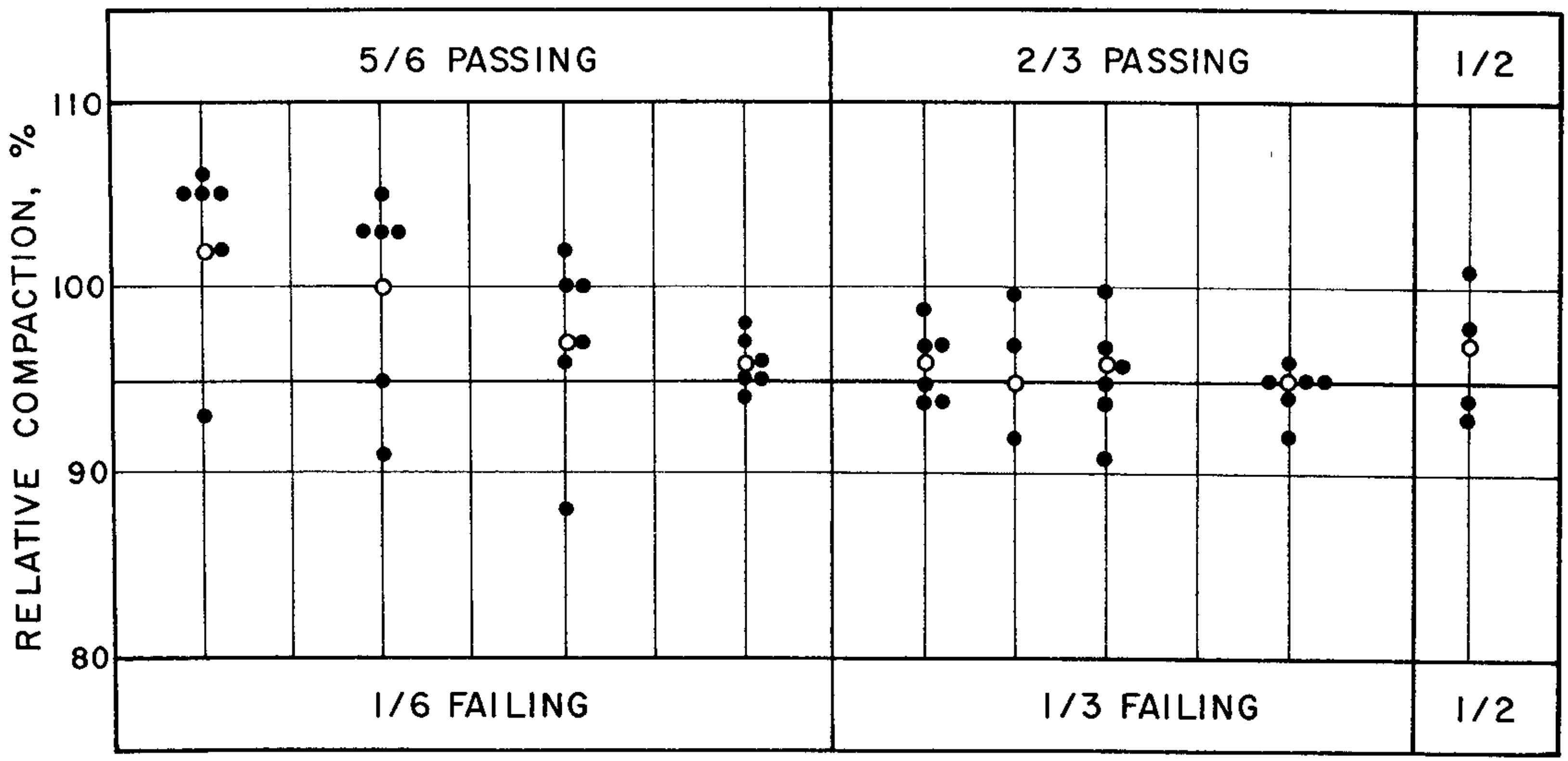
FIGURE 12

STRUCTURE BACKFILL, A.B. & A.S.

AREAS WHOSE AVERAGES MEET 95% MIN R.C. BUT CONTAIN INDIVIDUAL TESTS WHICH FAIL

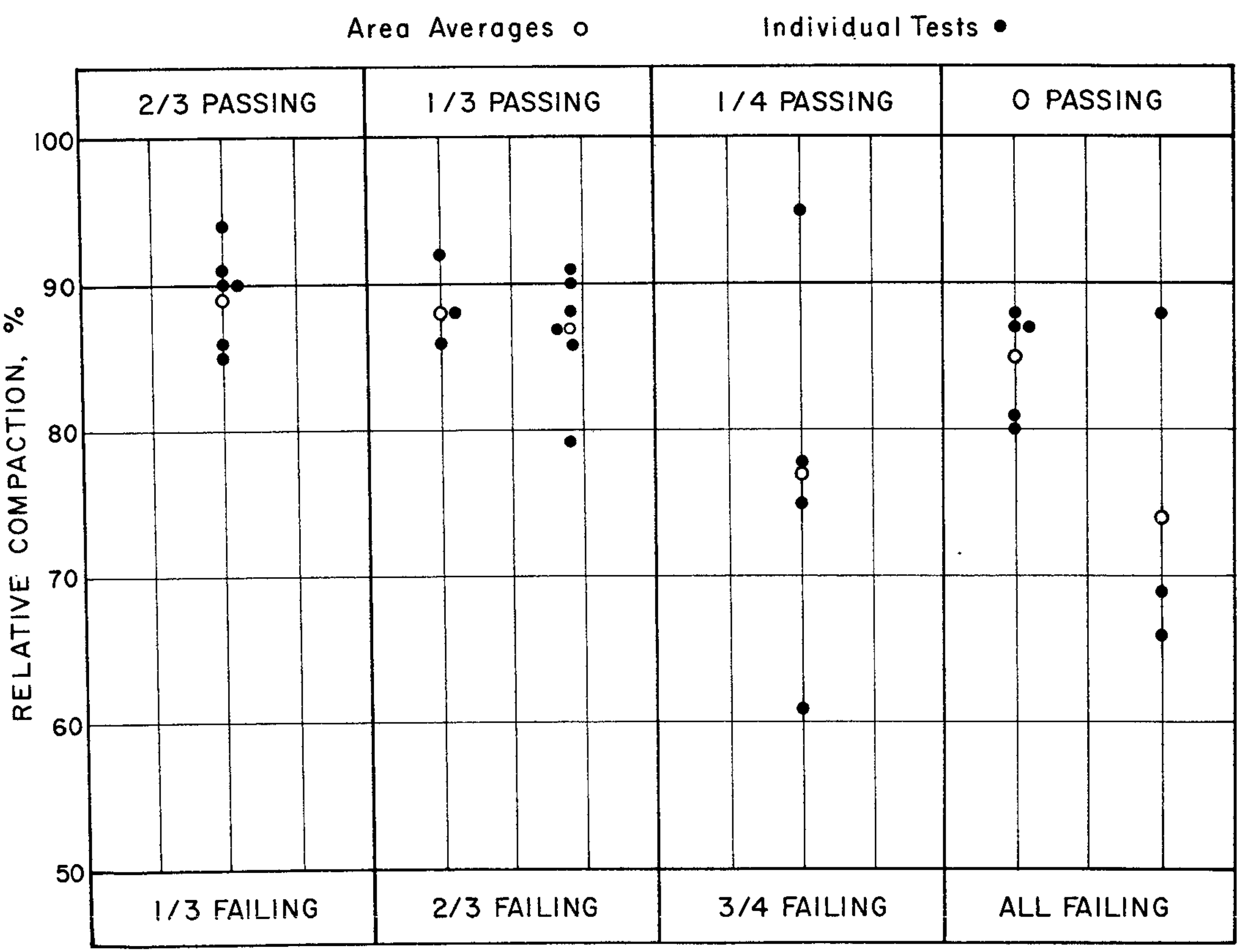
GROUPED IN PROPORTION OF PASSING TO FAILING VALUES

Area Averages o Individual Tests ●



EMBANKMENT

AREAS WHOSE AVERAGES <u>DO NOT</u> MEET 90% MIN R.C.



STRUCTURE BACKFILL, A.B. & A.S.

AREAS WHOSE AVERAGES DO NOT MEET 95% MIN. R.C.

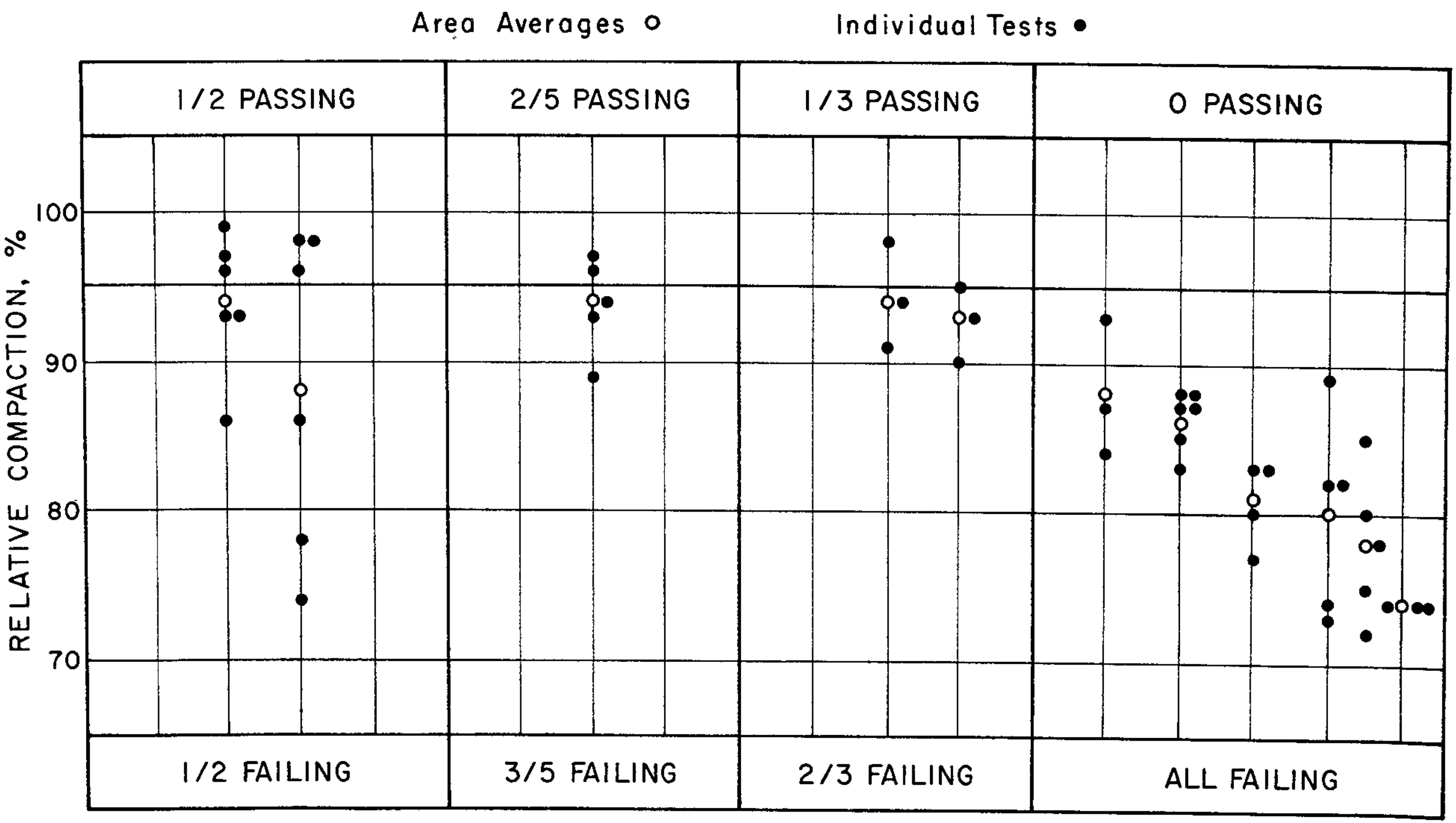
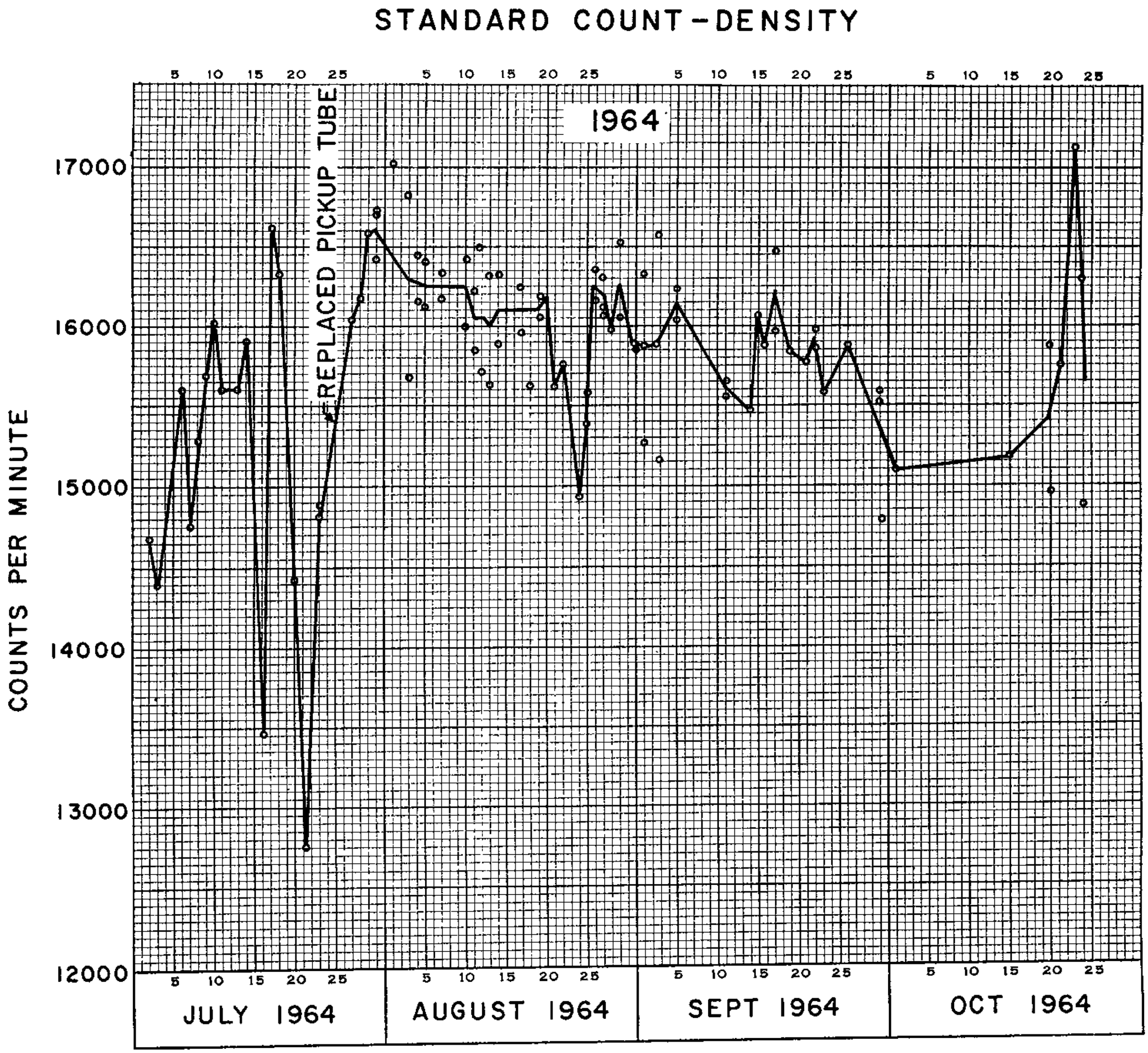
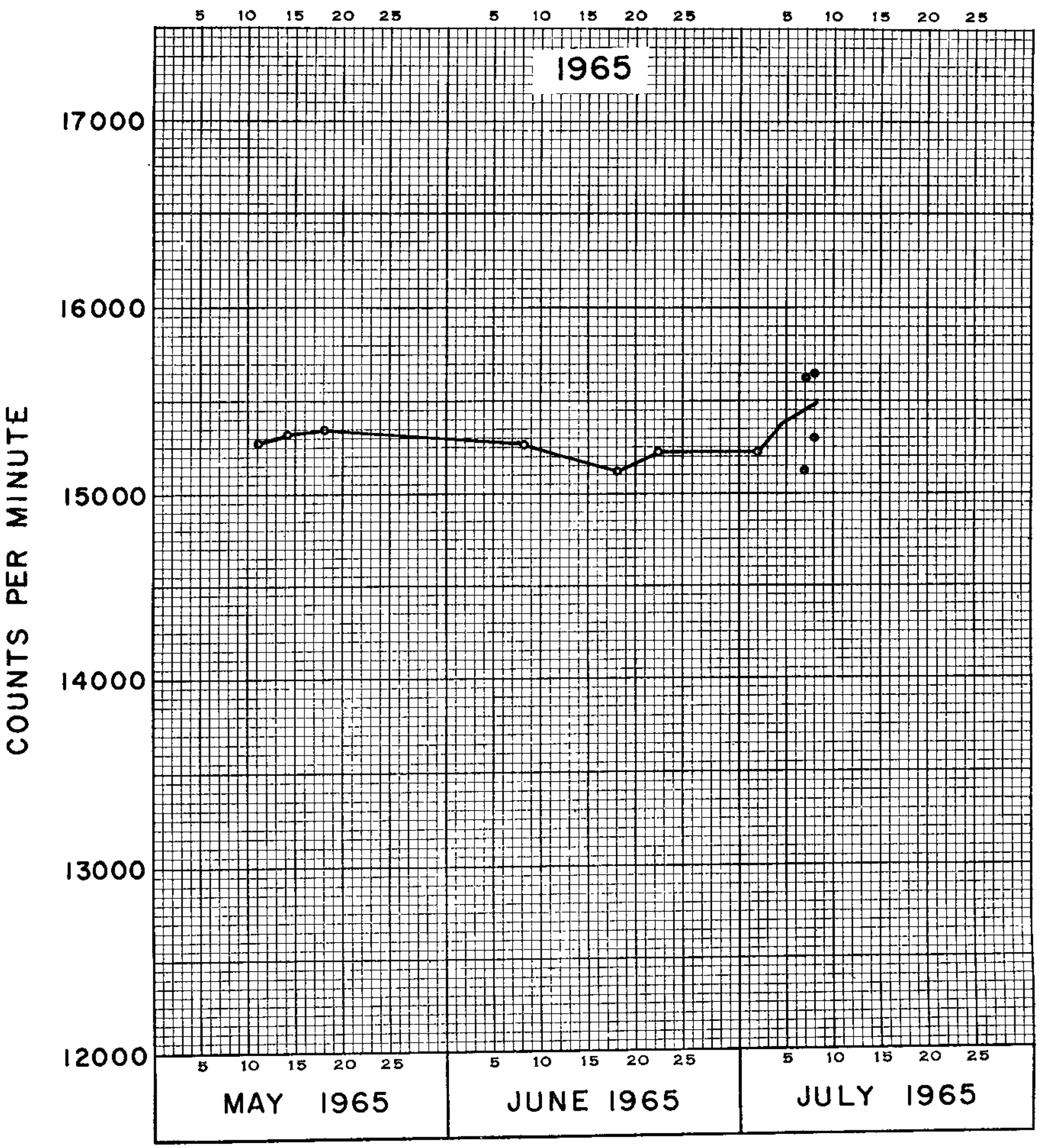


FIGURE 15


STANDARD COUNT-DENSITY
1964
REPLACED PICKUP TUBE
COUNTS PER MINUTE
17000
16000
15000
14000
13000
12000
5 10 15 20 25
JULY 1964
AUGUST 1964
SEPT 1964
OCT 1964

STANDARD COUNT-DENSITY



Test Method No. Calif. T 231-A
February, 1964
(3 pages)

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

METHOD OF TEST FOR RELATIVE COMPACTION OF SOILS BY NUCLEAR METHODS

SCOPE

The nuclear method of test shall be used to determine the in-place moisture and density of compacted soils. The in-place density is the density of a soil as it exists in either the natural ground or in constructed earthwork. The test maximum density shall be determined as specified in Test Method No. Calif. 216.

A. APPARATUS

1. A nuclear surface gage for determining soil moisture and density.

2. A portable scaler to count the radiation received from the nuclear gage.

3. A standardizing case to check the operation of the gage and scaler.

B. STANDARDIZATION OF EQUIPMENT

1. At least twice a day standardize the gage to check the operation of the equipment.

2. Place the gage upon the standardizing case and take counts after the scaler has been turned on for at least five minutes with the gage connected. Make five or more one-minute counts.

3. Discard any counts deviating from the average by over 200 counts and average the remaining counts. This average is to be within 250 counts of the average supplied with the equipment.

C. CALIBRATION

1. A calibration curve relating the counts obtained with the nuclear gage to the soil moisture and density will be supplied with the gage at the start of the contract.

C. CALIBRATION (Continued)

2. Obtain comparative sand volume tests at selected intervals at the same locations as the nuclear tests. Perform the sand volume test as described in Test Method No. Calif. 216.

3. After obtaining fifteen or more comparisons the calibration relating nuclear counts to density may be modified periodically by the method of least squares assuming a linear relationship.

D. DETERMINATION OF NUCLEAR COUNTS

1. Preparatory to making a nuclear determination, clear away all loose surface material and obtain a plane surface at least 2 feet square. In areas compacted by pneumatic-tired or smooth-wheel rollers, remove disturbed surface material to a depth of not less than 2 inches below the final surface on which the rollers have operated. Where sheepsfoot and similar type tamping rollers have been used, remove the loose surface material to a depth of not less than 2 inches below the deepest disturbance by the roller. The nuclear test may be conducted when the surface is plane to within 1/8 inch under the area covered by the gage.

2. Fill in the minor depressions, not exceeding 1/8 inch, with native fines. Place the nuclear gage on the soil surface so that all points of the bottom of the gage are in contact with the soil.

3. Obtain a reading over a one-minute interval. Then rotate the gage 90 degrees over the same center point and obtain another one-minute reading. If these two readings do not check within 250 counts, obtain two additional readings by rotating the gage over the same center point. Average the two or more readings which are within 250 counts.

E. DETERMINATION OF MOISTURE AND DENSITY OF THE SOIL

1. Using the calibration curve convert the averaged reading to wet density or moisture content. Show the wet density in pounds of material per cubic foot and show the moisture content in pounds of water per cubic foot.

2. Determine the dry unit weight by subtracting the moisture from the wet density.

F. DETERMINATION OF RELATIVE COMPACTION

The relative compaction shall be determined by either of the following:

1. Percent Relative Compaction

$$= \frac{\text{In-place dry density}}{\text{Test maximum dry density}} \times 100$$

Where

In-place dry density is determined by the use of the nuclear gages as herein described.

Test maximum dry density is determined as described in Test Method No. Calif. 216.

2. Percent Relative Compaction $= \frac{L_{(nuclear)}}{g_m} \times 100$

Where

$L_{(nuclear)}$ = in-place wet density as determined by the use of the nuclear gages herein described.

g_m = maximum adjusted wet density of the compacted test specimens as described in Test Method No. Calif. 216.

REFERENCES

Test Method No. Calif. 216

End of Text On Calif. T 231-A